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E. Giacomelli

LARGE GAS RECIPROCATING COMPRESSORS IN EUROPE

Enzo Giacomelli, Chief Engineer of the Reciprocating
Compressors Design Department, Nuovo Pignone, Florence, Italy

INTRODUCTION

The fact that, although its structural complexity, the reciprocating compressor is of great importance in gas compression in the chemical, petrochemical, as well as natural gas handling industry, is due to the continuous development of such a machine. This is the result of a careful research into more reliable solutions by the employ of materials and research means put by present technology at manufacturers disposal.
The European compressor manufacturing industry took part in such a development activity with original solutions which, sometimes, have to be considered as decidedly new. That is the instance of hypercompressors employed for the ethylene compression up to pressures of 3500 ats (50.000 psi) which had the European technique affirmed in the world, with special machines specifically designed for such an employ.
On the other hand, this supports the tradition according to which the European manufacturers (*) were the first to manufacture hypercompressors for ammonia synthesis production.
The fields particularly affected by the research into higher reliability, are the following:

- seals
- valves
- bearings
- drive
- pulsations and vibrations
- very high pressures

SEALING RINGS

In the past, at the first start-up of a reciprocating compressor, it was not unfrequent to have quick wear of sealing elements and of mating surfaces (liner and/or piston rod). This happened because in the compression of certain gases, lubrication may become precarious, either due to the effect of the diluting action of the liquids entrained by the gas, or to the effect of solubility of the oil in the gas.
This precariousness is accentuated by higher speed and pressure, since the need of lubrication becomes greater. Nowadays the problem may be considered solved by the use of filled PTFE for the piston rings, rider rings and rod packings.
A clear example of this is the use on ethylene primary compressors where filled PTFE seals have allowed 20,000 operating hours to be exceeded without maintenance, with differential pressures of about 300 kg/cm^2. (1)
Of course, for high pressure applications, it must be remembered that PTFE, since it is a plastic material, tends to extrude under pressure. It is therefore necessary to provide adequate back-up rings to avoid extrusion.
Rider rings of the split type obtain the best results. These have longitudinal grooves which, by allowing the free passage of the gas, prevent the rider rings from acting as piston rings. A device that has led to considerable lengthening of the life of these parts is the eccentric machining of the rider ring housing, with the axis displaced downwards with respect to the piston axis. In fact, in this way, the PTFE thickness to be worn is higher with a consequent considerable increase in the life of the rider ring.
It has been proved that every time PTFE was used to replace unsatisfactory metallic seals, the results have been fully satisfactory. This shows the soundness of the solution. Aleatory behaviour experienced in the past with metallic seals will no longer occur when adopting PTFE seals in the design stage. Thus critical conditions sometimes found during the first operating period of the plants will be avoided.
Two other advantages should also be noted as a result of the use of PTFE for seals.

- The oil quantity can be considerably reduced, compared with the quantity necessary using

(*) In the first ammonia synthesis plant, with the Casale process at 850 ats, constructed in 1922, a six stage compressor was used with a capacity of 1000 Nm3/h, designed and manufactured by Pignone of Florence (Italy).

metallic rings.

- Furthermore the use of PTFE, especially on the final stages, where metallic seals would require large amount of oil, allows an appreciable reduction in product pollution or poisoning of catalysts.
  Thus it is possible to use, without harm, oils having lower lubricating properties.

The achievement of high pressures with lubricated PTFE seals, has also encouraged the increase in pressure in the dry field.
Efficient friction heat removal and the use of proper fillers, together with a special design of the seals, allow dry PTFE to be used with satisfactory life, even for differential pressures up to 200 Kg/cm^2.

VALVES

Valves are the point where the development has been stronger in these recent years. In this field the technique passed from an empirical way to face the problem to the application of more scientific means like the use of mathematical models.
Europe has to thank for this development particularly the research work made by Prof. J.F.T. MacLaren and Dr. J. Brablik, who are known very well in this Congress.
It is now possible to predict with good accuracy the valve behaviour thus reducing very much the need of setting up at the start-up of the compressor and permitting an optimization between the compressor efficiency and the reliability.
This new approach in valve design is particularly useful in the manufacture of large reciprocating compressors whose application range is very wide and the manufacture of prototypes impossible.
Further research is however necessary into this matter to have in the future a still better correspondence between prediction and reality. Mutual influence of pressure pulsation and valve behaviour is one point of major interest of present investigation.

BEARINGS

It is now normal practice of the European compressor manufacturers to use bearings, with thin-layer antifriction metal. With them there is a minimum tendency toward damage of a steel journal under conditions of boundary lubrication or in dirty operation.
Often all bearings (main journal, connecting rod big end and small end) are of the three metal type.
These bearings have been demonstrated to be a good compromise between the fatigue resistance, the conformability and the embeddability. The adopted solutions on the compressors follow the experience gained by the European industry for big marine diesel engines which normally undergo more severe conditions specially in the two-stroke where there is no thrust reversal on the little end bearing.
Aluminium alloys are normally not employed because of their low embeddability, although their high fatigue resistance is known.
A development of the three-metal bearing is now represented by a further reduction of the babbit layer thickness. Tin-lead galvanic overlay of 0.04÷0.06 mm thickness start to be employed in large reciprocating compressors with further improvement of the fatigue limits which in fact tend to increase with the reduction of the babbit thickness. (2)
This, of course, requests a finer degree of filtration of the lubricating oil.

COMPRESSOR DRIVE

An interesting development in this field is represented by the drive of large process reciprocating compressors by means of steam turbine through a gearbox. (3). Such a solution is of course particularly interesting when steam is available on the plant.
This type of drive offers several advantages. A clear advantage lies in the possibility of reducing the capacity of the compressors by varying the RPM, which can be achieved simply and conveniently with a steam turbine. Owing to the nature of the reciprocating compressor, the pressure reached in the final stage is not affected by the RPM, and therefore the end pressure does not depend on capacity variations. Furthermore we can avoid the often complex and delicate devices, that must be installed on the cylinders when the RPM is constant, to reach the capacity control.
Reciprocating compressors, steam turbine driven, have been employed in many important plants like those for the production of ammonia, polyethylene and urea.
In this last case this type of drive represents a highly appreciated system because of the easy and rapid control of CO_2 delivered to synthesis.
In fact, it is well known that in urea production, the plant is fed simultaneously with CO_2 and liquid NH_3; the accurate dosing of these two reactants is very important.
The most efficient speed of the driver, in the power range concerned, is rarely lower than 6000 RPM; therefore a step-down gear box must be used.
Due to the high step-down ratios, nearly between 1/25 and 1/10, gear boxes usually have three shafts.
The coupling between compressor and gear-box must be designed bearing in mind the cyclic variation

in the compressor torque and the need that the consequent variations of angular velocity must not cause hammering in the gears. In order to obtain efficient protection, a flywheel is rigidly monted on the compressor shaft.
A further protection of the gears has been found in the use of the quill shaft, housed inside the hollow shaft, bearing the slow wheel of the gearbox.

PRESSURE PULSATION AND PIPING VIBRATION

During the last ten years a strong development has been made in the control of pressure pulsation by the using of analog simulators.
This analysis is now made on all large reciprocating compressors and enables the designer of the piping system around the compressor to reduce the pressure pulsation level avoiding dangerous acoustic resonances in it. An excess in the pressure pulsation level is in fact the first cause of dangerous vibration of the main piping, smaller connenctions and sometimes coolers, separators and other bottles.
The knowledge of the correlation between the pressure pulsation and the piping vibration is now under improvement, studying the mechanical behaviuor of the piping system under the action of the various harmonics of the pressure pulsation.
It is a hard job to simulate the action of the pressure and flow pulsation in terms of force on a certain branch of piping and to find experimental coefficients to represent correctly the anchoring effect of the supports.

VERY HIGH PRESSURE COMPRESSORS

As it has already been mentioned, over 50 years ago very high pressure started to be used in industrial processes. About 30 years ago much higher pressures (1500 + 3500 ats) (20000 + 50000 psi), entered the chemical plants for the production of low density polyethylene.
Many problems have been faced since then and many solutions have been used in a continuous development of design and manufacture. These problems consist mainly of:

1. the fatigue strength of the components subjected to a pressure fluctuating between that of suction and delivery;
2. the sliding seal between plunger and cilinder;
3. a mechanism to give almost perfect linear movement of the pistons

The first two points have been solved almost universally with the same methods. The fatigue problems of the cylinder components submitted to fluctuating pressure have been overcome by prestressing techniques like shrink-fitting or autofrettage and using, for the manufacture, very high quality steel (electro slag or vacuum arc remelted steel). The sealing action is normally obtained by using a packed plunger solution. Generally, solid sintered tungsten carbide plungers are used for the highest pressure while in other not extreme conditions coated plungers have been employed.
Packing performance and safety of operation with plunger of so brittle material is strictly connected with the thrust mechanism which has to assure an almost perfect linearity of the plunger motion. (4), (5)
Different ways have been followed by the compressor manufacturers. The tendency in Europe has been towards motion work designed specially for this particular service.
Other manufacturers have instead maintained the traditional crankmechanism, by introducing special additional systems to obtain thrust reversal, with certain disadvantages from the point of view of the compactness of machine.
Particular interest is related to the European patented (6) solution where two opposed pistons are driven through a special crosshead within which rotates the crankshaft and connecting rod. The crosshead guides are plain and placed very near the center-line. This solution gives a perfect thrust reversal and does not cause oscillation since the friction forces are almost on the center-line. The crosshead is very long with respect to the clearances, which are particularly small, and misalignment due to thermal expansion is avoided since the plunger axis and the slides are almost on the same plane. This solution would appear to meet the above requirements most satisfactorily. Furthermore, the crank mechanism, being composed of one very stiff member, does not require particular care in erection. The cylinder are placed on opposite sides of the crank mechanism and are therefore particularly accessible for maintenance.

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